

Final Report on NASA Grant NAGW5-1097:

MAMI:

Modeling of the Magnetosphere-Ionosphere-Atmosphere System.

1 May 1989 to 31 March 1998

Major emphasis of the investigation was the development of theoretical and numerical models of the aurora and of high latitude ionospheric processes. In particular,

- the NCAR TIGCM (Thermosphere-Ionosphere Global Circulation Model) was updated to include mid and low latitude electrodynamics (this version is called TIE-GCM);
- the NCAR TIE-GCM was modified to include a more realistic representation of the aurora;
- the UAF auroral electron transport model was modified to include local acceleration processes;
- a local ionospheric and auroral model (AURORA) was developed to allow detailed studies of the aurora;
- a proton-hydrogen transport code has been developed to model proton aurora;
- a theory for the production of suprathermal atoms and ions in the upper atmosphere was developed and applied to studies of atomic nitrogen transport and helium escape on open field lines.

These models enable us to devise schemes for the interpretation and quantitative analysis of data obtained by the POLAR spacecraft. Parameterizations were formulated and are available to the GGS investigators. The UVI and VIS teams have adopted these parameterizations and include them in their data analysis. We have developed software for the quantitative interpretation of UVI and VIS images. After the launch of the POLAR satellite we used the image data from UVI and VIS in combination with ground based data from SuperDARN and incoherent scatter radars, magnetometers, and *in situ* observations from DMSP and NOAA satellites to characterize the state of the ionosphere. A number of event studies have been carried out in cooperation with other GGS theory teams. The results of our investigation are published in refereed papers (see appended list) and were presented at numerous meetings, including AGU meetings, IUGG and IAGA conferences, and CEDAR workshops. The ISTP/GGS workshops were attended by the Principal and Co-investigators, and we contributed to various ISTP related workshops. We maintain a frequently updated web page (URL: <http://loke.gi.alaska.edu/mami/>) which also gives access to many of our results and papers. A detailed chronology of activities undertaken and results obtained has been provided in our semi-annual reports.

Two PhD theses were written with funding from this grant:

Shen, D., Proton transport and auroral optical emissions, PhD thesis, University of Alaska, Fairbanks, 1993.

Min, Q.-L., A self-consistent time varying auroral model, PhD thesis, University of Alaska, Fairbanks, 1993.

Published Papers (see also URL: <http://loke.gi.alaska.edu/mami/papers.html>):

- Rees, M. H. and D. Lummerzheim, Characteristics of Auroral Electron Precipitation Derived from Optical Spectroscopy, *J. Geophys. Res.*, **94**, 6799, 1989.
- Lummerzheim, D., M. H. Rees, and G. J. Romick, The Application of Spectroscopic Studies of the Aurora to Thermospheric Neutral Composition, *Planet. Space Sci.*, **38**, 67, 1990.
- Lie-Svendson, Ø., M. H. Rees, K. Stamnes, and E. C. Whipple Jr., The kinetics of "hot" nitrogen atoms in upper atmosphere neutral chemistry, *Planet. Space Sci.*, **39**, 929, 1991.
- Lummerzheim, D., M. H. Rees, D. J. Craven, and L. A. Frank, Ionospheric Conductances Derived from DE-1 Auroral Images, *J. Atm. Terr. Phys.*, **53**, 281, 1991.
- Rees, M. H. and D. Lummerzheim, Auroral Excitation Processes, in: Proc. Chapman Conference on Auroral Physics, Cambridge University Press, 1991.
- Lie-Svendson, Ø., M. H. Rees, and K. Stamnes, Helium escape from the earth's atmosphere: The charge exchange mechanism revisited, *Planet. Space Sci.*, **40**, 1639, 1992.
- Rees, M. H., Auroral energy deposition rate, *Planet. Space Sci.*, **40**, 299, 1992.
- Richmond, A. D., E. C. Ridley, and R. G. Roble, A thermosphere/ionosphere general circulation model with coupled electrodynamics, *Geophys. Res. Lett.*, **19**, 601, 1992.
- Roble, R. G., The polar lower thermosphere, *Planet. Space Sci.*, **40**, 271-297, 1992.
- Min, Q. L., D. Lummerzheim, M. H. Rees, and K. Stamnes, The Effects of a Parallel Electric Field and the Geomagnetic Field in the Topside Ionosphere on Auroral and Photoelectron Energy Distributions, *J. Geophys. Res.*, **98**, 19,223, 1993.
- Lanchester, B. S., J. R. Palmer, M. H. Rees, D. Lummerzheim, K. Kaila, and T. Turunen, Energy flux and characteristic energy of an elemental auroral structure, *Geophys. Res. Lett.*, **21**, 2789, 1994.
- Lummerzheim, D. and J. Liliensten, Electron Transport and Energy Degradation in the Ionosphere: Evaluation of the Numerical Solution, Comparison with Laboratory Experiments and Auroral Observations, *Ann. Geophys.*, **12**, 1039, 1994.
- Watermann, J., D. Lummerzheim, O. de la Beaujardière, P. T. Newell, and F. J. Rich, The Ionospheric Footprint of Magnetosheath-Like Particle Precipitation Observed by an Incoherent Scatter Radar, *J. Geophys. Res.*, **99**, 3855, 1994.
- Watermann, J., O. de la Beaujardière, D. Lummerzheim, J. Woch, P. T. Newell, T. A. Potemra, F. J. Rich, and M. Shapshak, The Dynamic Cusp at Low Latitude: a Case Study Combining Viking, DMSR, and Sondrestrom Radar Observations, *Ann. Geophys.*, **12**, 1144, 1994.
- Lu, G., A. D. Richmond, B. A. Emery, and R. G. Roble, Magnetosphere-ionosphere-thermosphere coupling: Effect of neutral winds on energy transfer and field-aligned current, *J. Geophys. Res.*, **100**, 19,643-19,660, 1995.
- Rees, M. H., D. Lummerzheim, and R. G. Roble, Modeling of the Atmosphere-Magnetosphere-Ionosphere System MAMI, *Space Sci. Rev.*, **71**, 691, 1995.

- Roble, R. G., On solar induced variability in the earth's upper atmosphere and ionosphere, in *Solar Drivers of Interplanetary and Terrestrial Disturbances*, ASP Conference Series, Vol. 95, (K. S. Balasubramaniam, S. L. Keil, and R. N. Smart, eds.), 609-618, 1995.
- Roble, R. G., Energetics of the mesosphere and thermosphere, in "The Upper Mesosphere and Lower Thermosphere: A Review of Experiment and Theory," *Geophysical Monograph*, **87**, 1-21, 1995.
- Blelly, P. L., A. Robineau, D. Lummerzheim, and J. Lilensten, 8-Moment fluid models of the terrestrial high latitude ionosphere between 100 and 3000 km, in *Solar-Terrestrial Energy Program: Handbook of ionospheric models*, ed. R. W. Schunk, 53, 1996.
- Lie-Svendson, Ø., and M. H. Rees, An improved kinetic model for the polar outflow of a minor ion, *J. Geophys. Res.*, **101**, 2415, 1996.
- Lie-Svendson, Ø., and M. H. Rees, Helium escape from the terrestrial atmosphere: The ion outflow mechanism, *J. Geophys. Res.*, **101**, 2435, 1996.
- Roble, R. G., The NCAR Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM), Ionosphere Models, STEP Handbook on Ionospheric Models ed. R. W. Schunk, Utah State University, 281-288, 1996.
- Peymirat, C., D. Fontaine, A. D. Richmond and R. G. Roble, The electrodynamic couplings between the thermosphere, the ionosphere and the magnetosphere, ESA Symposium Proceedings on Environmental Modelling for Space-based applications, ESTEC, Noordwijk, NL, 18-20, 1996.
- Doe, R. A., J. D. Kelly, D. Lummerzheim, M. Brittnacher, G. A. Germany, G. K. Parks, and J. F. Spann, Initial comparison of POLAR UVI and Sondrestrom IS radar estimates for auroral electron energy flux, *Geophys. Res. Lett.*, **24**, 999, 1997.
- Fuller-Rowell, T. J., M. V. Codrescu, R. G. Roble, and A. D. Richmond, How does the thermosphere and ionosphere react to a geomagnetic storm? *Magnetic Storms*, Geophysical Monograph 98, American Geophysical Union, 203-225, 1997.
- Germany, G. A., G. K. Parks, M. Brittnacher, J. Cumnock, D. Lummerzheim, J. F. Spann, L. Chen, P. G. Richards, and F. J. Rich, Remote determination of auroral energy characteristics during substorm activity, *Geophys. Res. Lett.*, **24**, 995, 1997.
- Germany, G. A., J. F. Spann, G. K. Parks, M. J. Brittnacher, R. Elsen, L. Chen, D. Lummerzheim, and M. H. Rees, Auroral Observations from the POLAR Ultraviolet Imager (UVI), AGU Monograph "Encounter Between Global Observations and Models in the ISTP Era", Jim Horwitz, Dennis Gallagher and Bill Peterson, editors, *in press*, 1997.
- Germany, G. A., G. K. Parks, M. J. Brittnacher, J. F. Spann, J. Cumnock, D. Lummerzheim, F. Rich, and P. G. Richards, Global Auroral Remote Sensing Using GGS UVI Images, AGU Monograph "Encounter Between Global Observations and Models in the ISTP Era", Jim Horwitz, Dennis Gallagher, and Bill Peterson, editors, *in press*, 1997.
- Lu, G., D. N. Baker, R. L. McPherron, C. J. Farrugia, V. K. Jordanova, D. Lummerzheim, J. M. Ruohoniemi, F. J. Rich, D. S. Evans, R. P. Lepping, M. Brittnacher, X. Li,

- R. Greenwald, G. Sofko, J. Villain, M. Lester, J. Thayer, T. Moretto, D. Milling, O. Troshichev, A. Zaitzev, P. Aleksandrovich, G. Marakov, V. Papitashvili, and K. Hayashi, Global energy deposition during the January 1997 ISTP event, *J. Geophys. Res.*, , *accepted*, 1997.
- Lummerzheim, D., M. Brittnacher, D. Evans, G. A. Germany, G. K. Parks, M. H. Rees, and J. F. Spann, High time resolution study of the hemispheric power carried by energetic electrons into the ionosphere during the May 19/20, 1996 auroral activity, *Geophys. Res. Lett.*, **24**, 987, 1997.
- Richmond, A. D., and R. G. Roble, Electrodynamic coupling effects in the thermosphere-ionosphere system. *Adv. Space Res.*, **20**, 1115-1124, 1997.
- Emery B. A., C. Lathuillere, P. G. Richards, R. G. Roble, D. J. Knipp, P. Wilkinson, M. Buonsanto, D. Sipler and R. Niciejewski, Thermospheric Neutral Response to the November 1993 Storm, *J. Atmos. and Solar Terr. Phys.*, *submitted*, 1998.
- Galand, M., J. Lilensten, W. Kofman, and D. Lummerzheim, Proton transport model in the ionosphere: 2. influence of magnetic mirroring and collisions on the angular redistribution in a proton beam, *Ann. Geophys.*, *accepted*, 1998.
- Lu, G., X. Pi, A. D. Richmond and R. G. Roble, Variations of total electron content during geomagnetic disturbances: A model/observation comparison, *Geophys. Res. Lett.*, **25**, 253-256, 1998.
- Lu, G., A. D. Richmond, Y. Kamide, D. Lummerzheim, M. Brittnacher, and G. K. Parks, Global ionospheric convection during substorm expansion, *Proc. Internat. Substorm Conf. 4*, , *submitted*, 1998.